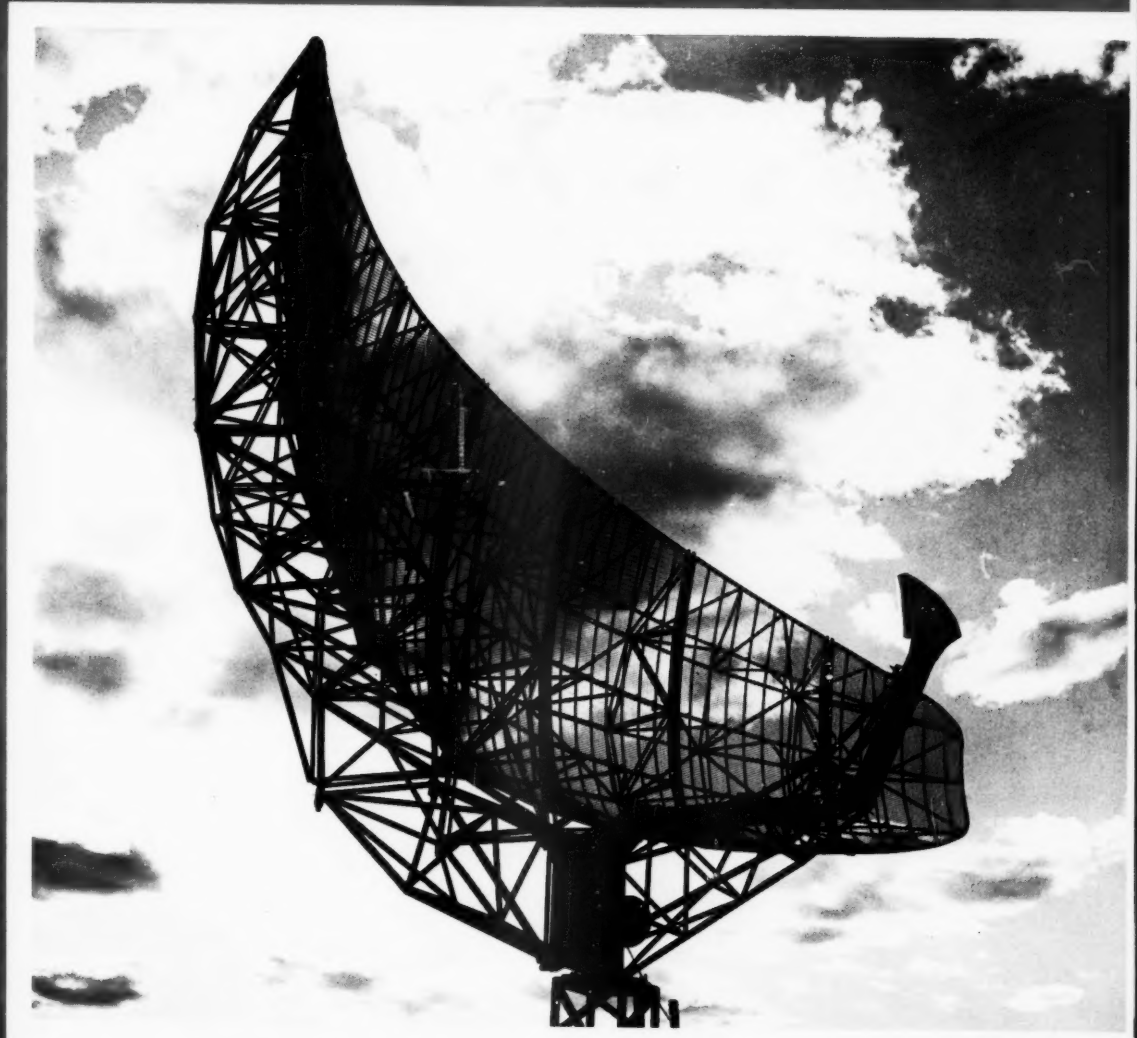
RAYTHEON

ELECTRONIC PROGRESS

MARCH
APRIL 1957



Raytheon's 40-foot L-band Antenna

In this issue: THE INFORMATION OBTAINABLE FROM A RADAR

ELECTRONIC PROGRESS

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RAYTHEON

ELECTRONIC PROGRESS

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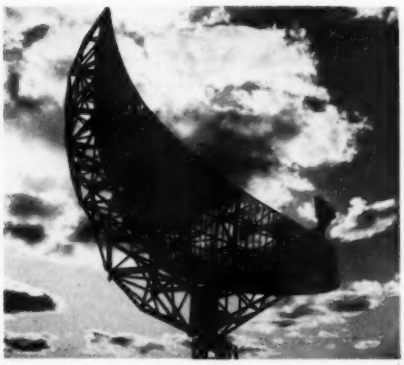
THE COVER



The 40-foot, high-gain, rotatable antenna shown on our cover is a story of government economy and Raytheon ingenuity. With this antenna the Company met the government's need for longer range radar and, at the same time, utilized already existing equipment. The 40-foot antennas, easily modified to work with any L-band radar, are being used with TPS-1D land surveillance radar which Raytheon originally developed and produced. Currently, the Signal Corp has ordered 109 40-foot antennas under a six million dollar contract.

Index

The Information Obtainable from a Radar	**W. M. Hall**	**1**
Elements of Pulse-Doppler Radar	**T. R. Silverberg**	**3**
Traveling Wave Tubes in Communication Systems	**W. E. Marcley and S. Topol**	**5**
Welding Committee	**R. C. Eckler**	**8**
Publications & Papers		**9**
Inventions		**9**

Calendar

Technical Committee Meetings

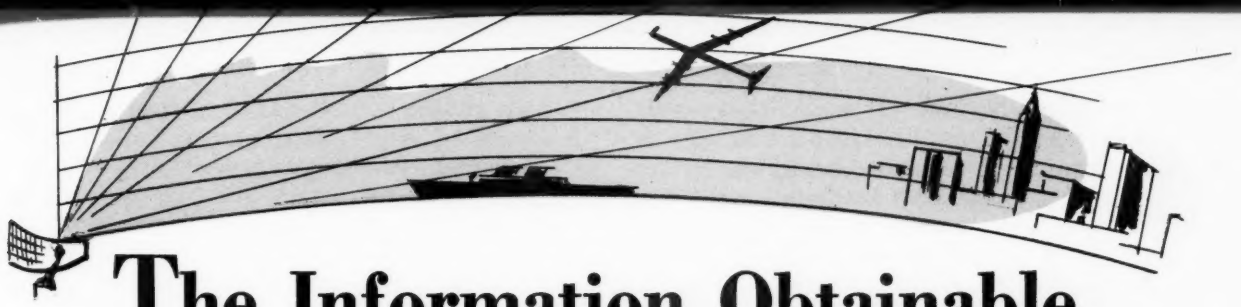
Course	*Place*	*Time and Date*
Plastics	**Varies**	**As required**
Ferrite	**Varies**	**1st Wed. of the month at 3:00 P.M.**
Transistor Circuit	**Research**	**As required**
Welding	**Varies**	**1st Thurs. of the month at 3:00 P.M.**
Magnetic Amplifier	**Wayland Laboratory**	**May 7, 1957**
Engineering and Scientific Co-ordinating Committee for Digital Computers	**Research**	**As required**

Other Seminars and Courses

Course	*Place*	*Time and Date*
Space Charge Seminar	**Research**	**As required**
Ceramics Seminar	**Research**	**Last Tues. of mo.**
"CW Radar" — T. A. O. Gross, Missile Systems Division, Raytheon		**Wed., March 6***
"Microwave Ferrite Devices" — H. Scharfman, Research Division, Raytheon		**Wed., March 27***
"Scatter Communication" — Prof. J. B. Wiesner, Mass. Inst. Tech.		**Wed., April 17***
"Computers in Control Systems" — H. A. Miller, Research Division		**Wed., April 3***

Place and Time — Wayland Cafeteria 5.20 p.m.

Technical and engineering personnel who desire further information concerning the above calendar should contact Mr. James Sterling, Research Division, Extension 2187.



The Information Obtainable From a Radar

W. M. HALL
Wayland Laboratory

What information can a radar provide and how rapidly can it provide it? What should be the characteristics of a radar so that it will give the most possible information, or so that it will meet some specific requirement? Why pulse, pulse-doppler, cw, fm, MTI (continuous wave, frequency modulation, moving target indication)? These are easy questions to ask. They are not easy questions to answer. The status of the search for the answers, rather than the answers themselves, is the topic discussed below.

Chronologically, pulse radar was the first type to come into large scale operational use during World War II. Short pulses of electromagnetic energy are radiated from a highly directional antenna. If this energy strikes an object in space, some of it is reflected and returns to the radar receiver. The distance to the object is determined from the time elapsing between the transmission and reception of the pulses and the known velocity of transmission of electromagnetic energy in the intervening medium. The direction of the object is determined by finding the heading of the antenna that results in the strongest signal return from the object.

The U.S. Air Force and Western Electric, prime contractor for the Arctic DEW Line, have selected Raytheon to develop the long-range radars for this vital network of early warning outposts in the frozen North.

CW radar is equally simple. If the reflecting object is moving toward or away from the radar, the frequency of the received signal will be higher or lower than the frequency of the transmitted signal. This is the familiar doppler effect, similar in principle to the apparent change in pitch of a locomotive whistle when it passes close by. By comparing the frequency of the returned energy with the frequency of the transmitted energy, the presence of a moving target can be detected. If the distance to the target is to be found, some form of modulation must be applied to the transmitted signal so that the signal transmitted at a particular instant can be "tagged", and the time of travel to and from the target can be determined. This leads naturally to fm radar.

The elementary principles by which information is gathered about a radar target are thus beginning to form. *Distance* to a target is determined by the time elapsing between the transmisison and reception of a signal. *Radial velocity* (rate of change of distance) can be determined by the change in frequency between transmission and reception. *Direction* of a target is determined by the direction from which the energy is returned.

But this is just the beginning of the explanation of the capabilities of a radar, and the problems confronting the radar designer. We know that different kinds of targets look different on the scope. What are these differences? What are the characteristics of one target that distinguish it from another? If there are many targets at or near the same range and in the same direction, is it possible to sort them? How much information can the radar really give?

In attempting to formulate answers to these questions, the following target characteristics must be considered.

1. Space characteristics. A single airplane differs from one thousand. Ships are on the surface of the ocean Cities are on land.

2. Time characteristics. Airplanes move faster than ships. Sea clutter fluctuates, i.e., the signals returned from the surface of the sea change as a

function of time, in a different manner than signals returned from a city.

3. Polarization characteristics. Airplanes and wet snowflakes depolarize the radiation more than do spherical raindrops.

4. Frequency characteristics. Targets presumably behave differently when viewed with radiation of different wave lengths.

A great deal is known about how to distinguish a signal from noise, that is, how to recognize the return to the radar receiver as being the result of the signal transmitted by the radar transmitter. This is associated with such impressive sounding words as "information theory" and "correlation". But amazingly little is known about how to tell one signal from another, that is, about the target characteristics listed above, and the ways and means of tailoring the radar to favor them.

Mast of the S.S. United States, showing antenna of the Raytheon 16 inch, model 1401, Mariners Pathfinder Radar.

There remains a threefold task.

1. The study of the characteristics of targets and how they modify or affect the radar signal.

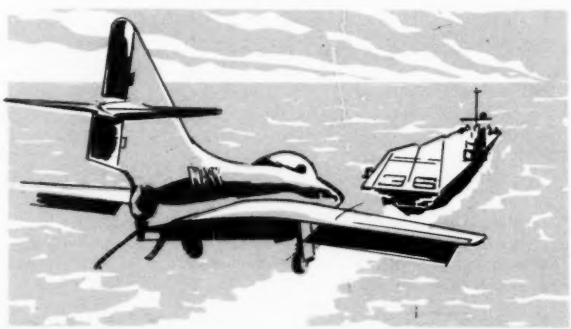
2. The study of how best to shape or control the transmitted signal so that the most useful information can be derived from it.

3. The practical problem of devising the physical equipment for generating the signals and for analyzing the output of the radar receiver and translating it into useful information.

The pulse radar of World War II was ideal for the simple problem of presenting a picture on a PPI — (plan-position-indicator) showing the location of ships and islands round about, as the problem of separating one signal from another by virtue of the fact that they arrive at different times is very simple. Elementary CW radar has its uses for detecting moving personnel among otherwise stationary targets. It is also quite ideally suited for use on very high altitude aircraft and missiles where the only return is from a "wanted" target, i.e., where there is complete freedom from groundclutter. The transmitter does not require the high instantaneous power of the pulse radar, but the separation of targets must be done with frequency-selective circuits. The receiver must operate while the transmitter is on, and small, distant targets must be detected in the presence of the return from large nearby ones. The pulse-doppler radar described in the following article is a logical compromise for many applications; it can sort targets by virtue of both their location and velocity. But in its present form, it is complicated by the need for separate data-processing circuitry for every range element, if the most possible information is to be derived from it.

Storage techniques, such as delay lines, storage tubes, and magnetic drums, make possible the storage of information so that one "processing" system may be used in turn, thus reducing this duplication. But these have their technical problems, and the only form in common use is the simple delay-line canceller "MTI" system, in which the return from one transmitted pulse is stored (delayed) for one pulse interval and compared with the return from the next succeeding pulse. If a target is moving, there will be change from one pulse to the next; if the target is stationary, the return on successive pulses will, ideally, be identical and will accordingly cancel out.

From the above it becomes apparent that different types of radars differ in their complexity and in their ability to separate targets in range and in velocity. They are bracketed by the simple pulse system which gives no velocity information and the pure cw system which gives no range information. If the simplifying assumption is made that the target is of constant size and is moving with constant velocity during the time of observation, and further that there are no other targets with which to confuse it, then it can be shown that the limiting detectability of that target is completely independent of the type of signal used — pulse, cw, fm, etc., but depends only on the total energy that



can be received from the target during the time of observation, and the thermal noise power per cycle of system bandwidth. (The limiting noise power is given by the product of Boltzmann's Constant times the absolute temperature times the Noise Figure of the receiver.) All of the usual types of radar approach this limiting sensitivity quite closely — within a few db. The closer together two frequencies are, which are to be separated or resolved in order to separate targets differing in velocity, the longer the required observation time will be; the shorter the pulses transmitted are, in order to separate targets differing in range, the wider the required spectrum will be. The separation of various kinds of polarization, and the interpretation of the fluctuation characteristics of the targets complicate the design problem still more.

There yet remains the need for a real analysis of the characteristics of different classes of targets, how best to shape the transmitted signal, and how best to go about processing the returned signal, so as to obtain the optimum combination of range information, velocity information, and information about the less well understood characteristics of the targets. Much must be done before we can say that we know how to design an optimum radar to distinguish one target from another with a minimum cost in terms of equipment and power. These problems are often overlooked in our zeal for more power, larger antennas, and more sensitive receivers.

Elements of Pulse-Doppler Radar

T. R. SILVERBERG

Wayland Laboratory

The term "pulse-doppler radar" has been used more and more over the past few years, often with little or no explanation attendant. This article sets forth, in simplified form, some of the basic principles of pulse-doppler radar, and refers to other sources for more detailed information.

Pulse-doppler radar usually is employed to sort out moving targets from fixed targets, and, as such, it is a form of MTI (Moving Target Indicator) radar. A simple pulse-doppler system operates as follows:

Because of doppler effect a radially moving target will create a shift in frequency of the returned radar energy. The resultant doppler frequency is twice the radial velocity of the target with respect to the radar divided by the operating wavelength and is represented by:

$$f_D = 2V/\lambda$$

Consider a pulse-doppler system which employs a single ranging-time interval equivalent in length to one pulse width. If this interval contains a radially moving target, the phase of the returned signal is compared with the signal phase that would have existed had the target not been moving radially. This can be achieved by various methods which are essentially phase-memory schemes. Among these are:

a. Comparison of the returned echo with the output of an echo box which was originally caused to ring by feeding part of the transmitted pulse into it.

b. Comparison of the returned echo with another returned echo, from a stationary target or from another target moving with a different velocity than the target in question, at the same range. This is the way in which a so-called noncoherent pulse-doppler system operates.

c. Comparison of the returned target echoes with a synthetic "fixed-target" echo, usually derived from what is termed a "stalo-coho" combination. The term "stalo" is a short form for "stable local oscillator" and the term "coho" is a short form for "coherent oscillator".

A radially moving target will change range slightly between one returned echo and the next, and the phase-memory system used will indicate the resulting different values of phase as they occur.

If the phase change between successive echoes is 0°, the target is stationary. In this instance the system will continue to deliver the same output value for every returned pulse, neglecting, of course, the effects of noise, propagation variations, and changes in received power as a result of the R^4 law. (This states that the signal strength varies inversely as the fourth power of the range.) With a stationary target the system output will be a succession or train of equal-amplitude pulses.

If, on the other hand, the target is not stationary, but is moving radially at some speed which leads to a phase shift *not* equal to 360°, the phase-memory system will indicate different values for the phases of successive pulses. The output of the phase-memory system for this target might look like Figure 1 over a period of 10 successive pulses. If this pulse train is analyzed, it will be found that the major frequency components occur at the doppler frequency and at the pulse repetition rate

(PRR) — the doppler frequency as shown in Figure 2. It will be found that doppler frequency is the frequency of the envelope of the pulse train of Figure 1 and is the same doppler frequency as defined previously. (An exception to this statement occurs whenever the true doppler frequency is higher than half the PRR. If this is possible, then the simple pulse-doppler system under discussion here will not indicate which of the sidebands corresponds to the true doppler frequency. A sideband is any one of the frequency components shown in Figure 2.)

One of the essential elements of a pulse-doppler radar is a bandpass filter. Consider such a filter with infinitely sharp cutoff characteristics at 0.1 PRR and 0.5 PRR. If the train of equal-amplitude pulses discussed above is fed into this filter, there will be *no* filter output. The two lowest frequency components present in this pulse train are at frequency 0 (DC) and PRR. Higher frequency components occur at all higher integral multiples of PRR.

Thus, if the pulse train of Figure 1, extended to sufficient length, is fed into the bandpass filter discussed above, the filter will show an output, provided that the doppler frequency is greater than 0.1 PRR and differs from PRR by more than this same value. (Note that if the doppler frequency is equal to 0.6 PRR, sideband A of Figure 2 will be located at 0.4 PRR and will be within filter limits. If the doppler frequency is between 0.9 PRR and 1.1 PRR, however, there will be no sideband within the filter limits.)

It is seen that the simple system just described will ignore targets exhibiting doppler frequency of less than 0.1 PRR and also those where the doppler frequency is between 0.9 PRR and 1.1 PRR. It will be sensitive to all targets exhibiting doppler frequency greater than 0.1 PRR but less than 0.9 PRR.

Land and sea return, in general, will exhibit low doppler frequencies. If all undesired targets inherently exhibit doppler frequencies of less than 0.1 PRR, and if it is not desired to detect a target which exhibits doppler frequency greater than 0.9 PRR, this simple system might be adequate*. It should be remembered, however, that PRR is a limiting factor on maximum range, as usually defined. From this consideration and from basic assertions made at the beginning of this article, doppler frequency, target radial velocity, operating wavelength, PRR, and maximum range are interrelated.

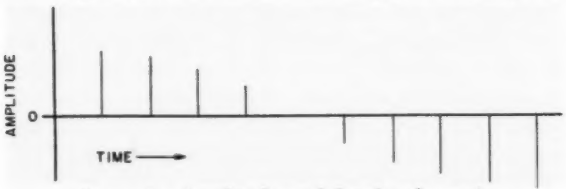


Figure 1 Amplitude-modulated pulse train.

Targets moving at certain radial velocities are not detected by the simpler forms of pulse-doppler radar. These targets are said to be moving at a "blind speed". Blind speeds occur whenever doppler frequency and PRR, or any integral multiple of PRR, are equal. Relating blind speed to doppler frequency, we find that the blind radial target velocity equals PRR, or any integral multiple of PRR, multiplied by the wavelength and divided by 2.

The fact that a blind speed occurs whenever doppler frequency equals PRR or any integral multiple thereof is inherent in a simple pulse-doppler system. In the phase-memory system described above, a target moving at blind speed would produce a phase change of 360° between any two successive pulses.

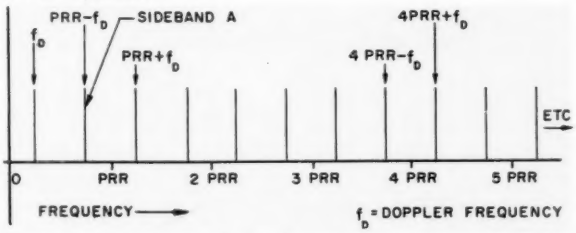


Figure 2 Location of the frequency components of the amplitude-modulated pulse train.

Techniques are available for dealing with the blind speed problem. For instance, one might switch from one PRR to a second on alternate scans, the ratio between the two PRR's being so selected that the first, or first few, blind speeds related to operation at one PRR would be filled in by operation at the second PRR thus extending the radial velocity coverage, or radial velocity response, of the system. This filling in of blind speeds can be done as a result of the inherent repetitiousness of blind-speeds in a simple (single-PRR) pulse-doppler system.

Other and more detailed discussions of pulse-doppler radar have been published in several technical magazines during the past three years. Remarks on basic MTI and pulse-doppler theory appear throughout the Massachusetts Institute of Technology's "Radiation Laboratory Series".

*Filter limits can be changed, of course, or can even be made adjustable. The lower limit could be set just above the doppler frequency of the interfering clutter — at 0.05 PRR, for instance. The system then would be sensitive to the doppler band greater than 0.05 PRR and less than 0.95 PRR.

Traveling Wave Tubes In Communications Systems

W. E. MARCLEY — S. TOPOL

Wayland Laboratory

The traveling wave tube (TWT) was developed in Great Britain during World War II. Since that time there has been much analysis, research, development and design but unfortunately, no major domestic communication equipment to date has been able to successfully apply the TWT. The reasons are many — some technical, some economic. This paper will endeavor to point to the future promise of the TWT in communications systems and specifically to relate what progress has been made at Raytheon in designing an equipment which uses them.

Although there have been microwave communications systems employing oscillators as final power tubes, the importance of using power amplifiers has become increasingly evident to designers of long haul systems. Cumulative distortions, oscillator instabilities and non-linearities have proven to be fundamental limitations which can best be overcome by utilizing the basic MOPA (Master Oscillator-Power Amplifier) principle at the terminals and some form of heterodyne or straight-through amplification at repeater points. At microwave frequencies below 4500 mcs, triodes are now in successful amplifier service. However, at these frequencies they suffer from gain-bandwidth and life difficulties, whereas at the higher microwave frequencies, the additional transit-time effects prohibit their use entirely. For this reason and for others we shall see later, velocity-modulated focused-beam tube types such as the TWT are now considered for replacement of the conventional grid-type density-modulated devices.

The TWT has basic similarities to the high-gain multi-cavity klystron amplifier, but because of its ability to utilize the velocity modulation principle without resonant elements, useful bandwidths of the order of an octave can be achieved. Unlike the klystron, the TWT has also found application in low-level receiver input circuits. Research over the past ten years has resulted in noise figures below 5 db at 3000 mcs.

These features, plus the fact that with careful design the cathode structure can be removed completely from any harmful life-shortening effects, have caused the communications system designer

Figure 1 Experimental Microwave repeater equipment using TWT amplifiers.

to consider the TWT seriously. From several viewpoints, then — high gain, large bandwidth, long life, low noise — the TWT looms as a desirable tube for amplifier service in communications systems. Why then should so many years pass before the TWT serves in the field? Part of the answer is technical — the problems of designing practical slow-wave structures, optimum focusing systems, and collector elements are not to be minimized. Part of the answer is economic — most tubes to date have been developmental, involving only model shop quantities and prices. But some of the answer is in the approach to the tube design problem. Although TWT's have occasionally been displayed as a simple glass or metal envelope, there must be included two other basic elements — the input and output couplers and the beam focusing structure.

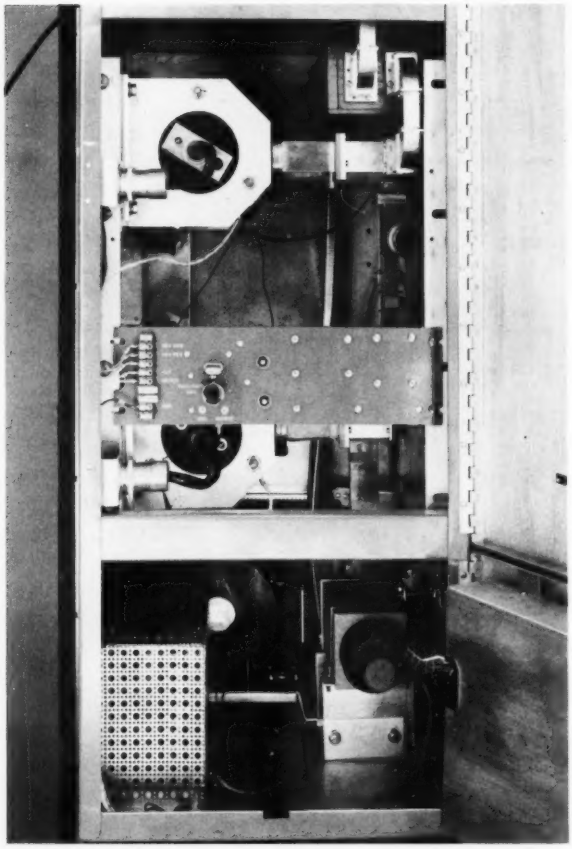


Figure 2 Interior view of R.F. Compartment of TWT repeater equipment.

Non-critical transformations to the helix must be developed, as well as simple focusing methods other than bulky, power consuming electromagnets. The tube designer is now aware of these requirements and is sensitive to field operation and maintenance problems.

At the Wayland Laboratory an experimental microwave repeater has been built which utilizes three traveling wave tube (TWT) amplifiers. This equipment is designed to serve at unattended relay stations of point-to-point microwave communications networks. An example of the application is the transmission of frequency-modulated color television signals over distances of several hundred miles by means of many relay stations spaced every 25 or 30 miles.

The operation of the TWT repeater can best be explained by referring to the block diagram given in Figure 3. A signal is received by a microwave antenna from the previous sending station. The input signal strength, which may be as low as 0.1 microwatt, is first amplified in a low noise type TWT. A waveguide pre-selection filter is used ahead

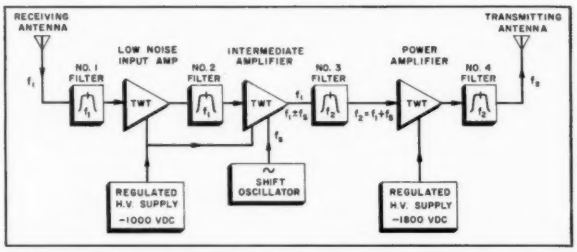


Figure 3 Simplified Block Diagram of a Microwave Repeater Using TWT Amplifiers.

of the input tube to reject spurious off-channel signals. . After the input tube a second bandpass filter tuned to the incoming frequency limits the noise bandwidth which, because of the broadband nature of TWT's, would otherwise be very great.

The second or intermediate TWT further amplifies the signal and also shifts its frequency by a pre-determined amount. This is done by phase modulating the helix of the TWT with the output of a crystal-controlled "shift" oscillator. At the TWT output, one of the first-order sidebands produced is selected by a waveguide filter and all other modulation components are rejected; (This sideband is, of course, displaced from the original signal by the amount of the shift oscillator frequency.) A similar technique of shifting frequency has been used previously with klystron amplifiers and is called "synchrodyning".

There are two reasons for wanting to shift frequency at a microwave relay station. The first is that it is desirable to stagger the sending frequencies of adjacent relay stations in order to avoid the possibility of a signal "overshooting" one station and causing interference at the next station beyond.

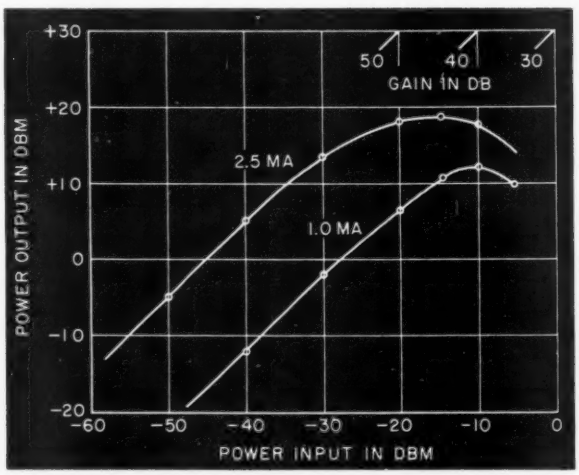


Figure 4 Output power of the Type A1059 TWT as a function of input power for two values of beam current. In the repeater the low noise input TWT operates at 1.0 MA, the intermediate amplifier operates at 2.5 MA.

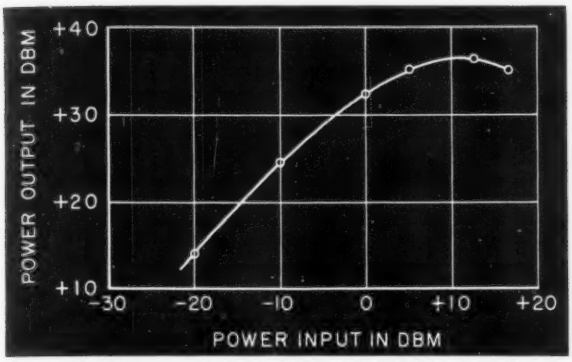


Figure 5 Power output as a function of input power for the QK-542 power amplifier TWT.

The second reason is to prevent self-oscillation of the repeater equipment. The high system gain and cross-coupling between antennas would be sure to produce oscillation unless the output frequency is different from the input and adequate filtering is provided.

The frequency shifted signal is then amplified to a final level of approximately five watts in the TWT power amplifier. A waveguide filter attenuates any off-channel radiation that may exist and the signal is then retransmitted to the next station. Table I summarizes the important performance characteristics of the repeater.

Table I: Performance Characteristics of TWT Repeater

Power Output	5 watts nominal (+ 37 DBM)
Frequency Range	5900–7400 Mcs
R.F. Bandwidth	30 Mcs
Normal R.F. Input Level	—30 to —70 DBM
Overall Gain	70–90 db
Noise Figure	less than 14 db
Input-Output Frequency Separation	100–150 Mcs

The traveling wave tubes which have been used in the experimental model of the repeater are themselves still in the development stage. A prototype of the Raytheon QK-542 was used for the power amplifier and the commercial type A1059 was used for both the input and intermediate amplifiers.

The Raytheon QK-542, although still in development, has many advanced features, such as metal envelope construction and permanent magnet focusing. Figure 5 shows proposed design characteristics of this tube type. The type A1059 TWT is a glass envelope tube which must presently operate in a large electro-magnet. The electrical properties of the A1059 are quite well suited to the application, however. Figure 4 shows the characteristics of this tube. It was possible to use it for both the low noise and the intermediate amplifier by adjusting the beam current to either optimize noise figure (low beam current) or obtain high gain (high beam current). This compromise was felt to be an important system advantage in reducing the number of different TWT types.

One other important characteristic of the TWT repeater is the system linearity. In comparison to other types of systems which de-modulate the signal before amplification, it is good. The TWT can, however, introduce certain types of distortion. For example consider the tube characteristics of Figure 4. It is obvious that if an amplitude modulated signal were operated in the saturated region, serious compression of the signal would occur. On the other hand, when a frequency modulated signal is being amplified, the saturation characteristic acts to limit unwanted amplitude changes in much the same manner as does the limiter of a conventional FM receiver. By intentionally adjusting the levels so that one or more of the repeater TWT's operates near saturation, it is possible to make the power output of the repeater quite constant over a wide range of input power levels. This is shown in Figure 6. For FM applications, this is most desirable in helping to counteract atmospheric fades in received signal strength.

A second type of distortion, however, often makes it necessary to keep the signal levels slightly below saturation, even for FM signals. It is known that the phase delay in a TWT is somewhat a function of input signal level — particularly in the saturation region. Therefore, if the incoming FM carrier contains any incidental AM modulation, it is possible

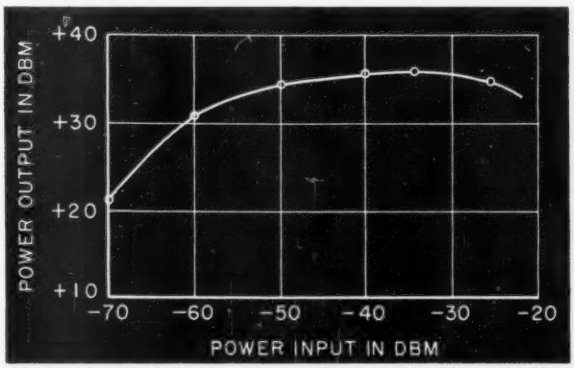
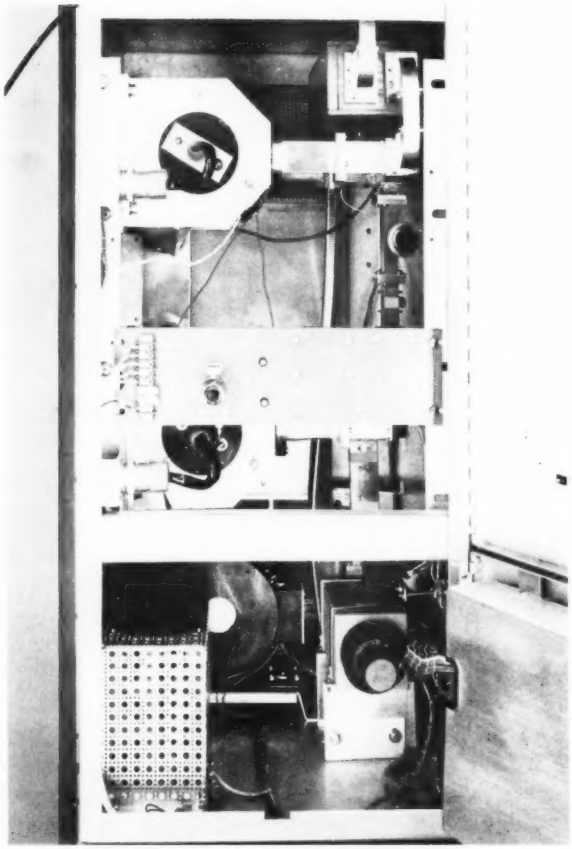


Figure 6 Repeater output power as a function of input power. Reasonably constant output results from operating last two TWT's near saturation. Further improvement is obtainable by using AGC.



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Non-critical transformations to the helix must be developed, as well as simple focusing methods other than bulky, power consuming electromagnets. The tube designer is now aware of these requirements and is sensitive to field operation and maintenance problems.

At the Wayland Laboratory an experimental microwave repeater has been built which utilizes three traveling wave tube (TWT) amplifiers. This equipment is designed to serve at unattended relay stations of point-to-point microwave communications networks. An example of the application is the transmission of frequency-modulated color television signals over distances of several hundred miles by means of many relay stations spaced every 25 or 30 miles.

The operation of the TWT repeater can best be explained by referring to the block diagram given in Figure 3. A signal is received by a microwave antenna from the previous sending station. The input signal strength, which may be as low as 0.1 microwatt, is first amplified in a low noise type TWT. A waveguide pre-selection filter is used ahead

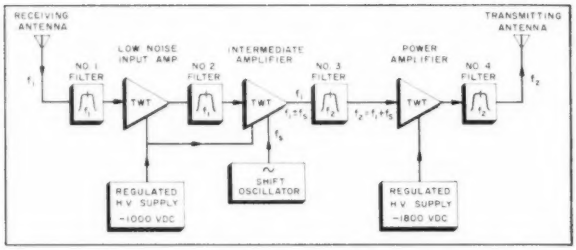


Figure 3 Simplified Block Diagram of a Microwave Repeater Using TWT Amplifiers.

of the input tube to reject spurious off-channel signals. After the input tube a second bandpass filter tuned to the incoming frequency limits the noise bandwidth which, because of the broadband nature of TWT's, would otherwise be very great.

The second or intermediate TWT further amplifies the signal and also shifts its frequency by a pre-determined amount. This is done by phase modulating the helix of the TWT with the output of a crystal-controlled "shift" oscillator. At the TWT output, one of the first-order sidebands produced is selected by a waveguide filter and all other modulation components are rejected; (This sideband is, of course, displaced from the original signal by the amount of the shift oscillator frequency.) A similar technique of shifting frequency has been used previously with klystron amplifiers and is called "synchrodyning".

There are two reasons for wanting to shift frequency at a microwave relay station. The first is that it is desirable to stagger the sending frequencies of adjacent relay stations in order to avoid the possibility of a signal "overshooting" one station and causing interference at the next station beyond.

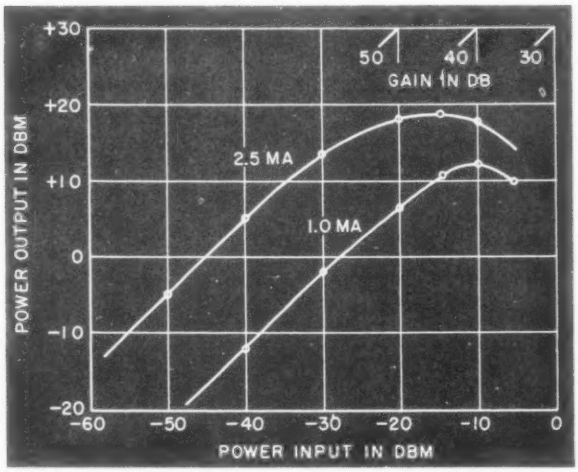


Figure 4 Output power of the Type A1059 TWT as a function of input power for two values of beam current. In the repeater the low noise input TWT operates at 1.0 MA, the intermediate amplifier operates at 2.5 MA.

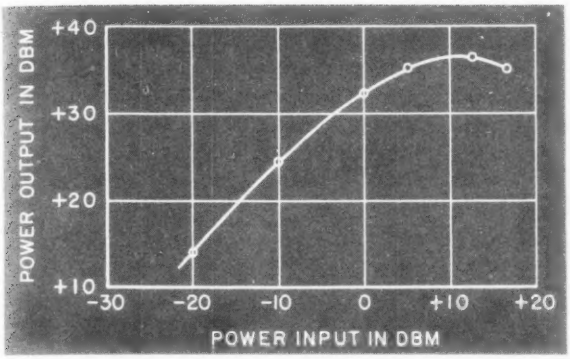


Figure 5 Power output as a function of input power for the QK-542 power amplifier TWT.

The second reason is to prevent self-oscillation of the repeater equipment. The high system gain and cross-coupling between antennas would be sure to produce oscillation unless the output frequency is different from the input and adequate filtering is provided.

The frequency shifted signal is then amplified to a final level of approximately five watts in the TWT power amplifier. A waveguide filter attenuates any off-channel radiation that may exist and the signal is then retransmitted to the next station. Table I summarizes the important performance characteristics of the repeater.

Table I: Performance Characteristics of TWT Repeater

Power Output	5 watts nominal (+ 37 DBM)
Frequency Range	5900–7400 Mcs
R.F. Bandwidth	30 Mcs
Normal R.F. Input Level	—30 to —70 DBM
Overall Gain	70–90 db
Noise Figure	less than 14 db
Input-Output Frequency Separation	100–150 Mcs

The traveling wave tubes which have been used in the experimental model of the repeater are themselves still in the development stage. A prototype of the Raytheon QK-542 was used for the power amplifier and the commercial type A1059 was used for both the input and intermediate amplifiers.

The Raytheon QK-542, although still in development, has many advanced features, such as metal envelope construction and permanent magnet focusing. Figure 5 shows proposed design characteristics of this tube type. The type A1059 TWT is a glass envelope tube which must presently operate in a large electro-magnet. The electrical properties of the A1059 are quite well suited to the application, however. Figure 4 shows the characteristics of this tube. It was possible to use it for both the low noise and the intermediate amplifier by adjusting the beam current to either optimize noise figure (low beam current) or obtain high gain (high beam current). This compromise was felt to be an important system advantage in reducing the number of different TWT types.

One other important characteristic of the TWT repeater is the system linearity. In comparison to other types of systems which de-modulate the signal before amplification, it is good. The TWT can, however, introduce certain types of distortion. For example consider the tube characteristics of Figure 4. It is obvious that if an amplitude modulated signal were operated in the saturated region, serious compression of the signal would occur. On the other hand, when a frequency modulated signal is being amplified, the saturation characteristic acts to limit unwanted amplitude changes in much the same manner as does the limiter of a conventional FM receiver. By intentionally adjusting the levels so that one or more of the repeater TWT's operates near saturation, it is possible to make the power output of the repeater quite constant over a wide range of input power levels. This is shown in Figure 6. For FM applications, this is most desirable in helping to counteract atmospheric fades in received signal strength.

A second type of distortion, however, often makes it necessary to keep the signal levels slightly below saturation, even for FM signals. It is known that the phase delay in a TWT is somewhat a function of input signal level — particularly in the saturation region. Therefore, if the incoming FM carrier contains any incidental AM modulation, it is possible

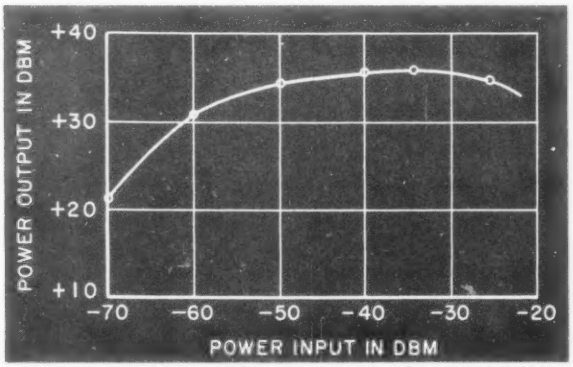


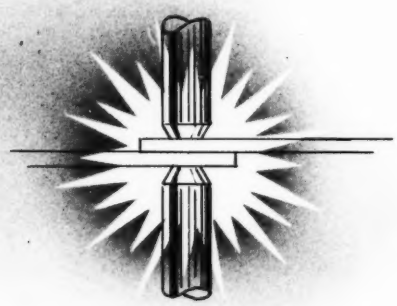
Figure 6 Repeater output power as a function of input power. Reasonably constant output results from operating last two TWT's near saturation. Further improvement is obtainable by using AGC.

to convert the AM to phase modulation and cause distortion. In practice, the TWT repeater is usually set up to compromise its best limiting properties with allowable "AM to PM conversion".

The simplicity of the system is particularly intriguing. The equipment that was built used only ten vacuum tubes, including TWT's, and the possibility exists for further reductions in that number. It is expected that the type of repeater that has been described here will prove to be an advance in providing lower distortion and greater reliability in microwave communications.

Welding Committee

R. C. ECKLER
Commercial Equipment Division



The Welding Committee, as such, was organized January 6, 1953, at the suggestion of Dr. I. A. Getting. The primary objective of the committee, as outlined by Dr. Getting, was to provide a means for exchange of technical information among various divisions of Raytheon. To this end, the committee meets monthly to discuss both the broad aspects of the welding field as they relate to the Company and also specific techniques and problems.

The general fields of metal joining which are normally covered by the committee include those of arc, resistance, gas and cold welding, as well as brazing and soldering. In these fields, discussions involving specific applications are held and usually cover one or more of the following: (1) recent advances in welding techniques; (2) processing problems; (3) metallurgy of joining processes; (4) availability, operation and maintenance of both commercial and special equipment; (5) quality control methods.

As a result of past committee discussions, the need for various welding equipment products has been established. Some of these products were later developed by the Equipment Engineering Division and are currently being produced by the Commercial Equipment Division. Notable among these products is the Heat Program Timer, which was developed as part of a contract for the Bureau of Ships and is considered to be one of the most versatile equipments being offered in the small spot welding field.

WELDING COMMITTEE

Division	*Name*
Microwave & Power Tube Operations	R. P. Allaire
Maynard Laboratory	H. R. Bullock
Administration	W. W. Drake, Jr.
Commercial Equipment Division	R. C. Eckler
Special Tube Division	E. A. Kolm
Special Tube Division	L. G. Lawrence
Missile Systems Division	M. F. McFadden
Research Division	H. A. Miller
Microwave & Power Tube Operations	J. A. Pekin

With regard to the promotion of educational activity, the committee, working through the Training Program Coordination Group, has been instrumental in arranging for a Company-sponsored course in Welding Engineering. This has been presented as a series of eight 2-hour weekly evening lectures, with an enrollment of 350 to date. The course was first offered during the summer months of 1956 and is currently being conducted as a revised and augmented course which started last fall. Mr. H. R. Bullock of the Maynard Laboratory is the lecturer for this series. Registration for the course has been open to interested personnel in the various divisions, and a certificate is awarded to those completing the course.

Much valuable experience along educational lines has been gained, even before the organization of the committee, by individual contributions of present committee members in their own divisions.

The committee is presently collecting material which will result in the issuance of welding information for general distribution, describing types of welds now being generally employed by the development and production groups of the various divisions.

Publications & Papers

"Internal Standardization"

R. G. MUNROE
Electronic Equipment Magazine

Abstract: (Parts I and II) Standards help to ensure *current adequacy* in components, engineering techniques, and production processes. Participation and consensus are essential in developing standards. The resulting publications help achieve effective use of engineering manpower. The three major responsibilities of a company standards program are (1) developing new standards in advance of the need for them; (2) retirement of obsolete standards; (3) revision and service to existing standards. (Part III) The pressures encouraging electronic progress are generating conditions contributing to unsatisfactory equipment reliability. The company standards program is a major managerial tool for improving reliability.

"Plastic Tooling"

A. I. SIMON
Franklin Technical Institute

January 17, 1957

Abstract: The talk covered some uses of plastics in tooling. The plastic materials included were cast plastics, reinforced plastics, foams, plastic honeycomb and sandwich type structures. The topics presented included: methods of fabrication of different types of plastic tools, jigs and fixtures; thermal dimensional change phenomenon associated with a heterogeneous cylindrical reinforced plastic gage and thermal expansion properties in flat glass fabric reinforced laminations. A demonstration of the actual fabrication of a plastic drill jig was given by Andres Rodrigues (of the Plastics Group-Research Division).

"Broadband Waveguide-to-Coax Transitions"

G. J. WHEELER
IRE National Convention

New York, March 18-21, 1957

Abstract: This paper describes three transitions from waveguide to coaxial line, each of which covers a frequency range of more than 30%. These include:

1. A transition from WR 159 waveguide to 50 ohm coaxial line with a VSWR $\leq$ 1.14 from 4400 to 7000 mc. This is a "normal" transition in that the coaxial line feeds into the center of the broad face of the waveguide.
2. A colinear end-on transition from RG 48/U waveguide to standard 50 ohm 7/8" coax with VSWR $\leq$ 1.10 from 2600 to 3700 mc.
3. A colinear end-on transition from 2.840" x 0.875" i.d. waveguide to standard 50 ohm 7/8" coax with VSWR $\leq$ 1.13 from 2600 to 3800 mc.

"Field Test Equipment For Airborne Radar"

W. W. KEITH and F. E. SEARS, III
IRE National Convention

New York, March 18-21, 1957

Abstract: The use of skilled electronics personnel is minimized, equipment reliability is improved, and down time is reduced by means of an adequate field test equipment program. An example is given of a field test equipment for an airborne radar which features: runway equipment, for quick preflight tests at the aircraft without use of an oscilloscope, and for maintenance tests to localize trouble to a major unit of the radar; the test equipment also features hangar equipment, for go-no go tests of hermetically sealed modules such as the I.F. amplifier, A.F.C. and servo amplifier. Self-testing circuits detect failure of the test equipment.

"Rare-Earth Oxide Cathodes"

L. J. CRONIN and J. APELBAUM
IRE National Convention

New York, March 18-21, 1957

Abstract: In the field of physical electronics, there is need for electron emitting materials which will compete or improve on existing designs utilizing thorium dioxide. With this in mind, investigations were conducted on the following rare-earth materials — gadolinium oxide, neodymium oxide, samarium oxide, lanthanum oxide, didymium oxide, and combinations of these and other oxides. Measurements on these materials for thermionic emission data were taken in simple diodes with the emitting material held in a molybdenum mesh. Processing of the materials and of the vacuum diodes are described. Values are given of the D.C. and pulse emission data. These data are reported as a function of life and in comparison with a standard 100% thoria cathode. The results indicate this class of materials offers definite possibilities as useful cathode materials.

"A Broadband Fixed Coaxial Power Divider"

J. REED and G. J. WHEELER
IRE National Convention

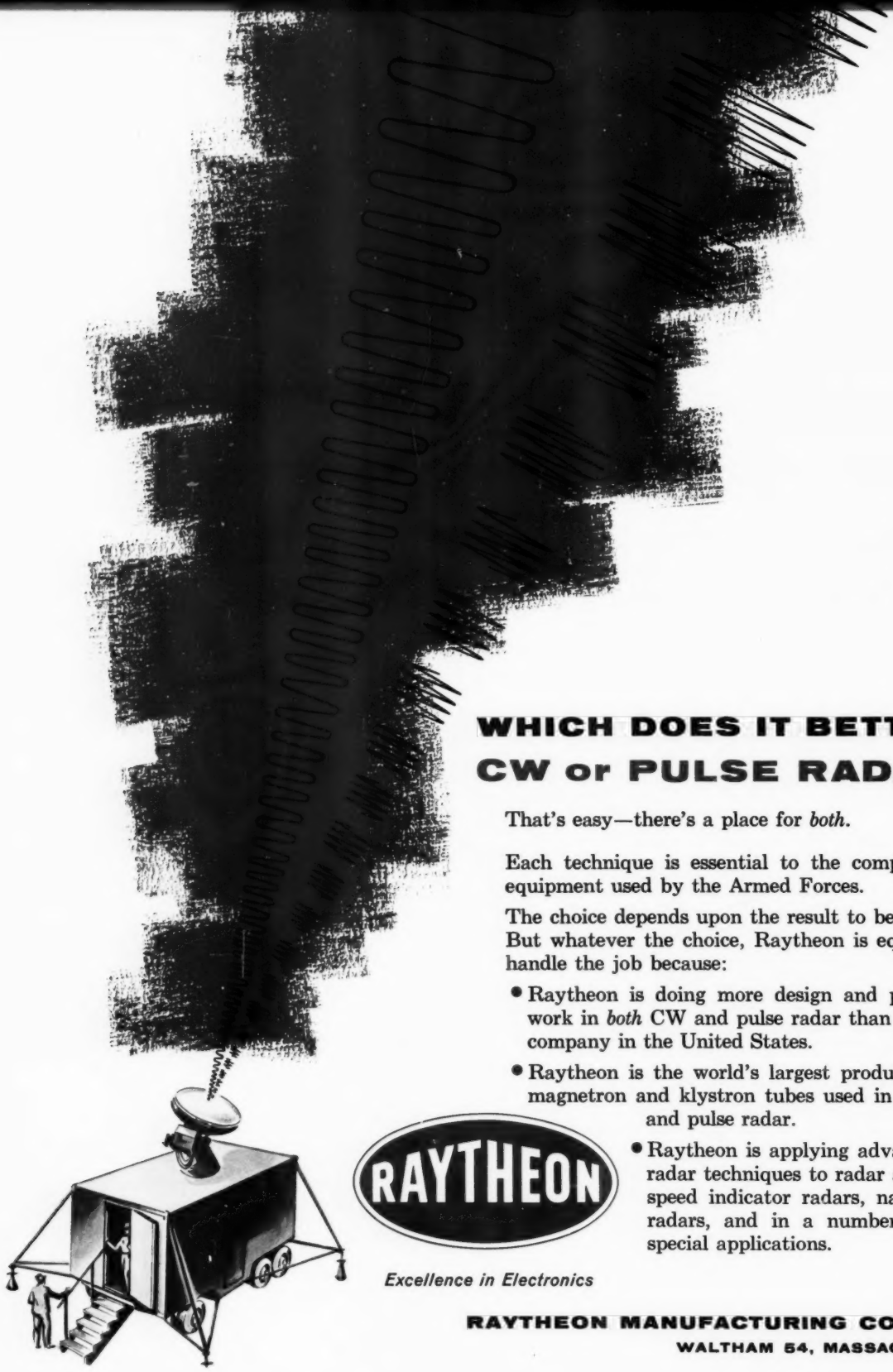
New York, March 18-21, 1957

Abstract: The design of a coaxial line power divider of any fixed power division ratio and maximally-flat performance is described. The performance of an actual model is tested over a 30% band by the Deschamps method as well as other schemes and a comparison of these schemes described. The design includes a stub support so the device will stand high power. A refinement to the existing theory is discussed.

Inventions

Congratulations to the following persons for their valuable contributions to Raytheon's portfolio of inventions:

Name	*Field of Invention*
Herman Chin	Etching Vibrator
Frank Corey	Feed Through Terminal
Leo Cronin	Metal-to-Carbon Seal
Edward Dench	Magnetron Amplifier Radar System Carcinotron Injection Locked Oscillator
Gim Fong R. L. Mondano A. I. Simon	Thermosetting Plastic
Niles Gowell	Interaction Frequency Converter
Leon Greenberg	Small Junction and Contact Control
Robert Harper & Robert Unger	Brazing Technique
Henry B. Maloney	Sealing-in Machine Tinning Machine
Henry B. Maloney & Walter Russo	Pencil Tube Tubulation Machine
William Maitland & N. V. Sutherland	Magnetic Shielding
Willard McLeod, Jr.	Ferrite Modulator
James Spencer	Lamination Welding
Hugh P. Taylor	Diode Rate Counter
John Williams	Bar-Type Transistor



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- Raytheon is the world's largest producer of the magnetron and klystron tubes used in both CW and pulse radar.
- Raytheon is applying advanced CW radar techniques to radar altimeters, speed indicator radars, navigational radars, and in a number of other special applications.

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